1.0 INTRODUCTION

1.1 Background

The California Air Resources Board (ARB) Indoor Air Quality and Personal Exposure Assessment Program is working to identify and reduce Californian's indoor and personal exposure to air pollutants. To meet this goal, the ARB requires data on emissions from various air pollutant sources and the resultant personal exposure and indoor air concentrations in selected microenvironments. Data collected by the ARB can be used to improve estimates of human exposure to selected Toxic Air Contaminants in a variety of microenvironments and to develop guidance for Californians to help them reduce their exposure to air contaminants.

Various studies have identified cooking as a potentially significant source of indoor air pollution and personal exposures. Cooking has been reported to be a major source of particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), and other organic compounds in ambient air due to emissions from commercial cooking operations (Rogge et al., 1991; Schauer et al., 1998; and Schauer et al., 1996). Cooking has also been identified as a significant source of PM in residential dwellings (Brauer et al., 2000; Brauer et al., 1996; Ozkaynak et al., 1996; Ross et al., 1999; Wallace, 1998, 1996a, and 1996b). PAHs have been reported in fumes from cooking oils (Chiang et al., 1997; Shields et al., 1995; Shuguang et al., 1994; and Wu et al., 1998). Measurements in residences have shown increases in levels of PAHs associated with cooking (Chuang et al., 1991; Dubowsky et al., 1999; and Sheldon et al., 1993). Air contaminants may be emitted from the cooking appliance (Rogge et al., 1993; Rogge et al., 1997) and the cooking process (Annis and Annis, 1989; Rogge et al., 1991; Gerstler et al., 1998). Epidemiological studies have found significant associations between increased respiratory symptoms and the presence of, or cooking with, a gas range (Pope et al., 1995; Zhong et al., 1999).

Despite the recognition that cooking may be an important source of air contaminants in residential dwellings, emissions from cooking and the resultant exposures have not been well characterized. To meet its goals, the ARB required data to gain a better understanding of the impact of cooking on indoor air concentrations and personal exposures to air contaminants generated by cooking in residences. The current study was initiated to address those data needs. The ARB developed a design for a study to collect data on pollutant emissions and exposures from a wide range of cooking activities. The study objectives and design are described below. The current study represents the first large-scale study of various cooking emissions and exposures in a residential setting under semi-controlled conditions. Results from the study will provide a better understanding of the impact of cooking and will be useful for developing further research in this area of exposure.

1.2 Study Objectives

The goal of the project was to characterize the pollutant emissions and the potential human exposure impact from a range of residential cooking activities. The specific objectives of the project were the following:

- Characterize emission rates and resultant indoor air concentrations and personal exposures for particulate matter (PM), carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO_2) produced by residential cooking under typical and realistic worst-case conditions
- Characterize emission rates and resultant indoor air concentrations for other cooking pollutants such as PAHs, elements, and other potential marker compounds
- Measure the effectiveness of selected exposure reduction practices

1.3 Study Design and Project Overview

The project objectives were addressed in an original study design submitted to the ARB in the ARCADIS Geraghty & Miller (ARCADIS) Technical Proposal. The plan was subsequently refined in consultation with ARB staff and members of a Technical Review Group (TRG, listed in Appendix B) that was formed to provide technical input to the study. The study design is outlined in the *Revised Study Design and Test Plan for Indoor Air Quality: Residential Cooking Exposures*, dated November 12, 1998. The project consisted of the following ten tasks:

- Task 1 – Review the literature and study design
- Task 2 – Meet and consult with the Technical Review Group and the ARB to finalize the study design
- Task 3 – Obtain a Test House in California where the tests will be performed
- Task 4 – Prepare the Test House for the study and perform a pre-test
- Task 5 – Conduct testing of cooking activities
- Task 6 – Test exposure reduction methods
- Task 7 – Perform data processing and analysis
- Task 8 – Prepare draft final report
- Task 9 – Prepare final report
- Task 10 – Present project seminar

A literature review was performed at the start of the project in an attempt to identify additional information that could be used to refine the study design, test protocols, or measurement methods. The ARB had already performed a literature review and identified the major peer-reviewed literature on the subject in their request for proposal. The literature review was performed using both computerized and manual search methods. At the time of the review (Fall, 1998), there was little information identified by ARCADIS beyond that already identified by the ARB. The bibliography for the literature review is included as Appendix A of the report.

The literature review did not result in any significant changes to the study design. Minor modifications were made to the study design based on discussions with the TRG and ARB staff. These modifications were incorporated in the study design referenced above. The following is a brief overview of the project. More detailed information is presented in the following sections of the report.

A test house was rented in Rohnert Park, California for the study. The house was a small single-story ranch style home constructed in the 1970s. It met a large number of the criteria for selection of the test house, as described in Section 2.0. The small size of the house (less than 1000 ft^2) and the layout of the rooms resulted in good air mixing in the house even though the house air handler was not operated during testing. The house had an attached garage where a laboratory was located. The test house was specially instrumented for the study. Temperature and relative humidity (RH) sensors were placed in selected rooms and outdoors. Temperature sensors, a power transducer, and a dry gas meter were installed on the ranges to collect data during cooking tests. Teflon® sampling lines were routed to the kitchen (K), living room (LR), master bedroom (MBR), and outdoors (OA) for collection of air contaminants. A second set of sampling lines was routed to the same rooms for collection of SF_6, the tracer gas measured to calculate air exchange rates. A laboratory was set up in the garage with pollutant monitoring instrumentation, a data acquisition system, and support hardware for instrument calibrations.

A pre-test was performed in May 1999 to test the instrumentation, sampling methods, and test protocols. The pre-test involved initial measurements of CO, NO, and NO_2 to characterize the performance of the gas range before and after tuning. The methods and results for the tuning are included in Appendix D.

Four cooking tests were then performed. Duplicate tests were performed that involved frying loose ground beef in a pan on the range top burner. A second set of duplicate tests was performed that involved preparation of a pork roast in the oven of the gas range. Results of the pre-test are summarized below and included in an electronic database accompanying the report.

The main cooking study was performed in February 2000, when the temperatures were moderate, to avoid the need for operation of an air conditioner during the cooking tests. The main study involved 32 cooking tests at the house in Rohnert Park. The tests involved cooking with an electric range, gas range, and microwave oven. The microwave was used in three of the tests and measurements were performed only with real-time monitoring methods (continuous monitors for CO, NO, NO_2 and PM). The electric range was used for seven cooking tests. These same seven cooking activities were performed with the gas range for comparison. All other tests were performed with the gas range. Parameters measured during all tests, except with the microwave, included the following:

- CO, NO, and NO_2 with continuous pollutant monitors
- PM concentrations and size distributions (12 size fractions from 0.04 to 8.4 μm, aerodynamic mean diameter) with an electrical low pressure impactor (ELPI) that recorded data continuously
- $PM_{2.5}$ and PM_{10} mass, collected on Teflon® filters with size selective inlets,
- Air exchange rates
- Temperature and RH indoors and outdoors
- Range top burner and oven temperatures
- Gas or electric use during cooking

During selected tests, additional samples were collected for other air contaminants. These included samples for PAHs, elements, and aldehydes. Although fatty acids were originally proposed for measurement during the project, they were dropped from the main study. Samples were collected for aldehyde measurements instead because results from other studies (Theibaud et al., 1994, Schauer et al., 1998 and Kelly, 2000) suggested that cooking with the oven and broiler resulted in substantial emissions of carbonyl compounds.

The 32 tests were designed to collect information on the following factors:

- Appliance type (gas, electric, and microwave)
- Cooking method (frying, baking, broiling, range-top burner, oven)
- Food type (variety of foods cooked)
- Cooking vessel (pan material, lids)
- Exposure reduction methods (exhaust fan, hood shields)

1.4 Pre-Test Summary

The pre-test involved a set of four tests during which all measurements were performed and samples were collected for all target parameters. The tests, which involved relatively short duration cooking events, were designed to determine the performance of the sampling and analytical methods. The tests were performed in duplicate to assess the variability and method precision. The results of the pre-test are presented in the electronic database accompanying the report. Results of the pre-test and issues identified in the pre-test included the following:

- $PM_{2.5}$ mass concentrations ranged from below the minimum detection limit (MDL) in one outdoor sample to 1040 $\mu g/m^3$ in the kitchen during one of the tests with pan frying of loose ground beef
- PM_{10} mass concentrations ranged from 9.9 to 11.8 $\mu g/m^3$ outdoors and 25 to 144 $\mu g/m^3$ indoors during the four cooking tests
- Results of the pre-tests indicated that the cooking protocol should be changed to increase the amount of PM mass that could be collected by the integrated sampling methods. The average mass of PM on the filters for all samples collected during the pre-test was only 100 μg. Mass on the filter samples collected outdoors was near the limit of detection due to the short sampling periods. This was because the cooking period for pan-frying of ground beef lasted only 20 minutes, and the total exposure duration during which the samples were collected was only 2 hours long. Although the sampling period was longer for the pork roast in the oven (4.3 hours), the total mass collected was still low because of the lower emissions during this cooking activity.
- Real-time measurements of particle concentrations in the 12 size fractions with the ELPI indicated that the particles were predominantly in the smaller size fractions (less than 0.5 μm). This observation suggested that additional measurement methods, such as a scanning mobility particle sizer (SMPS), would be required to characterize the particle size distribution. An SMPS was not available for the study, and the ELPI represented the best single piece of instrumentation for measurements over a wide range of particle sizes.

- PAH concentrations were low and below the limit of detection in many of the samples. Few compounds were detected in samples collected during the short beef pan-frying tests. PAH levels were generally higher indoors than outdoors. PAH concentrations in the living room were not substantially different from those in the kitchen, suggesting that sampling should be limited to the kitchen. Precision was poor for duplicate samples. The poor precision and large number of samples with non-detectable PAHs suggested that the cooking periods and sampling durations should be longer.
- The elements measured by X-ray fluorescence (XRF) in PM_{10} samples were typical of ambient air particles, predominantly comprised of silicon, aluminum, sulfur, calcium, and iron. Chlorine was also detected frequently at this location, which was near the ocean. Although copper and zinc were detected in over two-thirds of the samples, there was no clear trend of higher indoor concentrations. Due to low mass levels on the filters, there was poor precision for the duplicates. As for the other parameters measured by collection of integrated samples, the data suggested that the data quality would be improved if cooking protocols were modified to facilitate collection of higher levels of PM mass.
- CO, NO, and NO_2 emissions were consistent with published results for gas ranges
- Indoor temperatures in the house ranged from 17.0 to 26.8 °C. Indoor relative humidity during the pretest ranged from 32.4 to 61.7%. Air exchange rates ranged from 0.31 to 1.07 air changes per hour

Results from the pre-test were used to refine the study design. The primary change was to develop cooking protocols that incorporated either cooking of multiple batches of food during a single cooking event or performing two sequential cooking events during which a single set of integrated air samples were collected.